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HELICOPTER FLIGHT DIRECTOR SYSTEMS
FROM OPERATOR'S REQUIREMENTS TO PRODUCTION HARDWARE

by

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ABSTRACT OF PAPER NO. 57

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The authors of this paper present a unique insight into helicopter flight directors. By occupation they are a senior design engineer, a program manager and an operations manager. All are pilots. The paper reviews the history at KLM which led to the operational requirements for an improved helicopter IFR capability. It also looks at the measures taken by KLM to solve the problems involved in off shore helicopter operations and describes the hardware to be used in its S-76 fleet.

The technical side of the paper provides insight into the problem associated with integrating flight directors with a wide variety of sensors. A block diagram shows the system switching and interface. The use of simulation in programming the Flight Director computer is discussed briefly, as is coupling the computer to the flight control system. Finally the paper discusses some controversies concerning Flight Directors and what we can expect in the next generation.

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I. Operations Background

Since the beginning of operations in 1968, KLM Helikopters B.V. has offered its services to the oil-industry and harborpilot service on a 24 hour, 7 days per week, basis. For this purpose, IFR procedures were developed and certified with the Dutch Civil Aviation Authority (RLD) for the S-61N before starting operations (ref. 1). In 1969, the IFR capability of the S-61N was further improved by the development and certification of the Airborne Radar Approach to oilrigs and ships (ref. 2).

In 1973, the company initiated a further study of the possibilities to improve pilot and system performance. It indicated that a reduction of the certified weatherminima was not possible with the original "close scan" instrumentation-layout (ref. 1), because the workload for the average pilot would become unacceptable. The study therefore concentrated on finding ways and means to exploit the unique IFR potential of the helicopter more fully with a system that would significantly reduce the pilot's workload. It would, in principle, provide the capability to conduct ILS and Radar Approaches to CAT II weatherminima or lower without having to revert to costly automatic guidance and fixed wing procedures.

The system which was eventually chosen for evaluation on the S-61N was an Integrated Pilot Display System. A prototype was manufactured by Kaiser Aerospace and Electronics for the military, and modified to KLM specifications. The Electronic Display provided the possibility of reducing instrument cross check to a minimum. The evaluation of this system took place in 1975/76. It proved beyond doubt that the basic concept was sound and capable of achieving certification of weatherminima below fixed wing CAT II limits without automatic guidance (ref. 3).

When the Sikorsky S-76 (Spirit) was selected for introduction into the company in 1979/80, a decision was also made to install a complete flight director system to take full advantage of the IFR capability of this aircraft. However, because the Kaiser Aerospace equipment had not reached the certification and production stage, alternative possibilities had to be studied. As a result of this study, Astronautics Corporation of America (ACA) was selected to provide the equipment. ACA was already producing flight director systems for the Sikorsky Black Hawk. This system was readily adapted to the KLM and RLD requirements except for the use of an electronic display, which was not cost effective at this state.

II. Operations Requirements

The ACA system is able to:

A. Conduct ILS and Radar approaches, as well as conduct take-off's below fixed wing CAT II weatherminima without automatic coupling to the controls.

B. Reduce pilot's workload by displaying computed commands on one instrument. It also provides as much other information as possible on this instrument to reduce instrument scanning to a minimum during the critical flight phases.

C. Reduce the pilot's workload en route, in particular in controlled areas. To meet the RLD requirements for CAT II operations (ref. 4) without coupling, dual, independent flight directors have to be installed. The RLD requires two pilots for Airline Transport Operations.

1. To achieve the required capabilities a flight director was designed by Astronautics with the following modes:

Off	Heading	Go Around
Altitude Hold	VOR/ILS Approach Deceleration Auto Manual Level Off	MLS
Back Course	Air Speed	Descent

By using a combination of one or more of these modes the helicopter can be flown at the safest combinations of air speeds and altitudes to accomplish the mission. The unique attributes of the helicopter can be exploited and yet the pilot's work load is reduced to a very low level because of the computations made by the computer and the compact display of essential information.

The deceleration mode is normally used if the approach is made over water or flat terrain, as is the case for ILS approaches in the Netherlands.

The Manual Deceleration mode is required for:

(a) Approaches over undulating terrain

(b) For radar approaches where the deceleration should take place at a certain distance from the rig (Fig. 1); and

(c) For ILS approaches when weather conditions do not require an airspeed reduction.

Either deceleration mode can be engaged in any but the Go-Around mode, and can be terminated at any time by engaging Airspeed-Hold, thus providing flexibility for any desired approach procedure.

The ILS Localizer steering command can accept crab-angles up to 45°. This should be sufficient to cope with an increase in crab-angle when decreasing airspeed and allow approaches to runways which are not used by fixed wing aircraft, because of a high cross wind component. High winds, however, will not present a problem, because foggy weather conditions are not normally experienced in high wind conditions.

The Go-Around mode can also be used as a Take-off mode or a Climb-mode, as it will command a climb at 500 ft/min. at 80 kts IAS. The Go-Around mode can be engaged by pressing a button on the cyclic control. A light on the Attitude Director Indicator (ADI) will show that the mode has been engaged. To enable a change of heading while in the Go-Around mode, the pilot may select the new desired heading on the HSI and then follow the vertical command bar on the ADI.

When the helicopter reaches a preset radar altitude on the radar altimeter, a Level-off command is automatically engaged, over-riding all other vertical command inputs, except Go-Around. In this way, it is possible for the pilot to preset the radar altitude for leveling off at varying decision heights on the final phase of the Radar Approach. Furthermore, a Descent mode has been included which, together with an Airspeed mode, commands a descent at 500 ft/min at any desired airspeed. This mode is mainly intended to be used in the intermediate phase of the Radar Approach but may also be useful for a VOR/DME approach.

For the future, provisions have been made for an MLS (MADGE) mode.

The single Flight Director Computer Mode Select Panel (Fig. 2) utilizes dual switches with each single mode button. This will preclude a switch failure immobilizing both FDC's.

2. To provide the closest possible scanning of instruments the ADI incorporates most of the clues and crosschecks required for the critical phases of the approach.

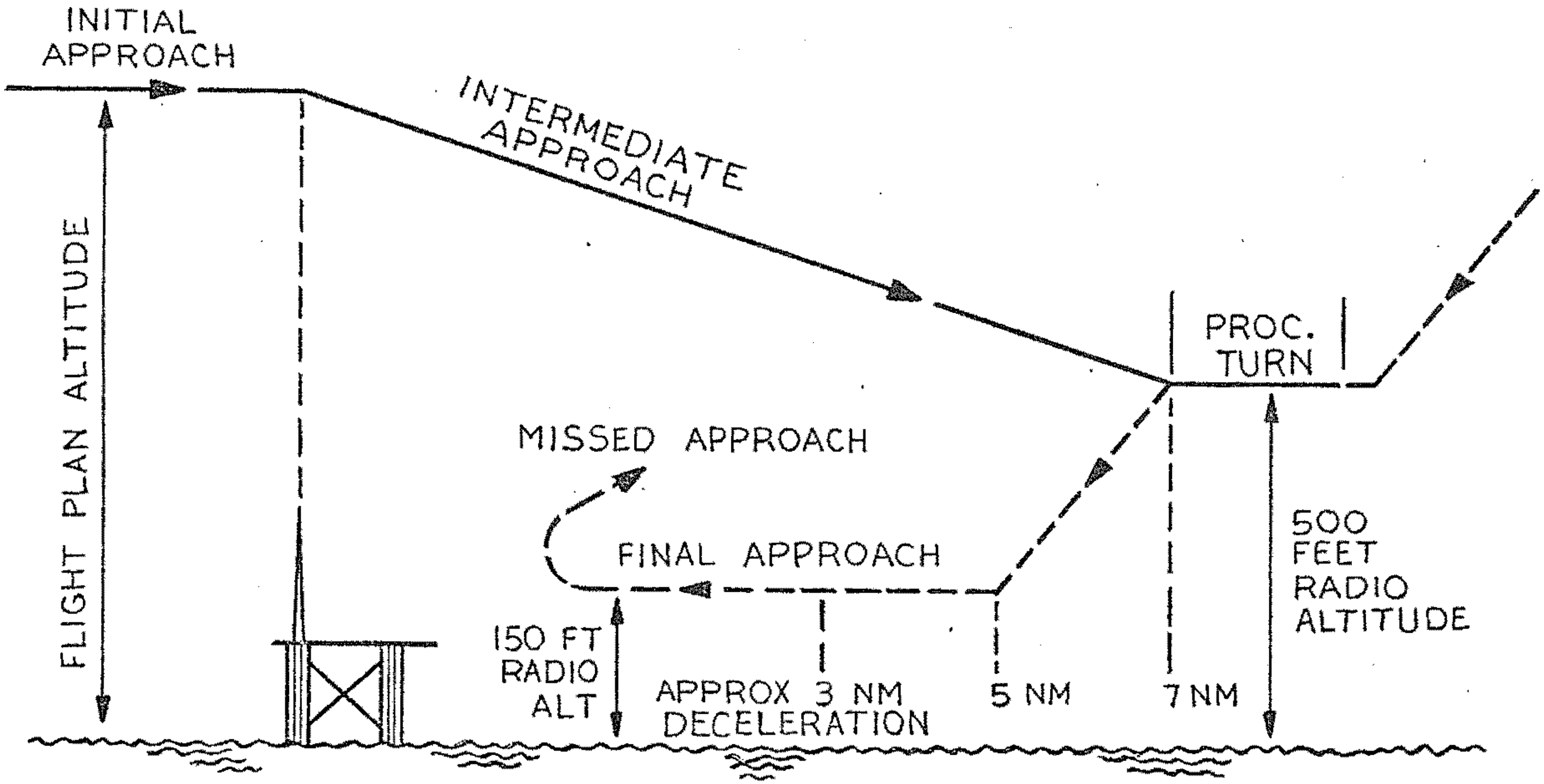
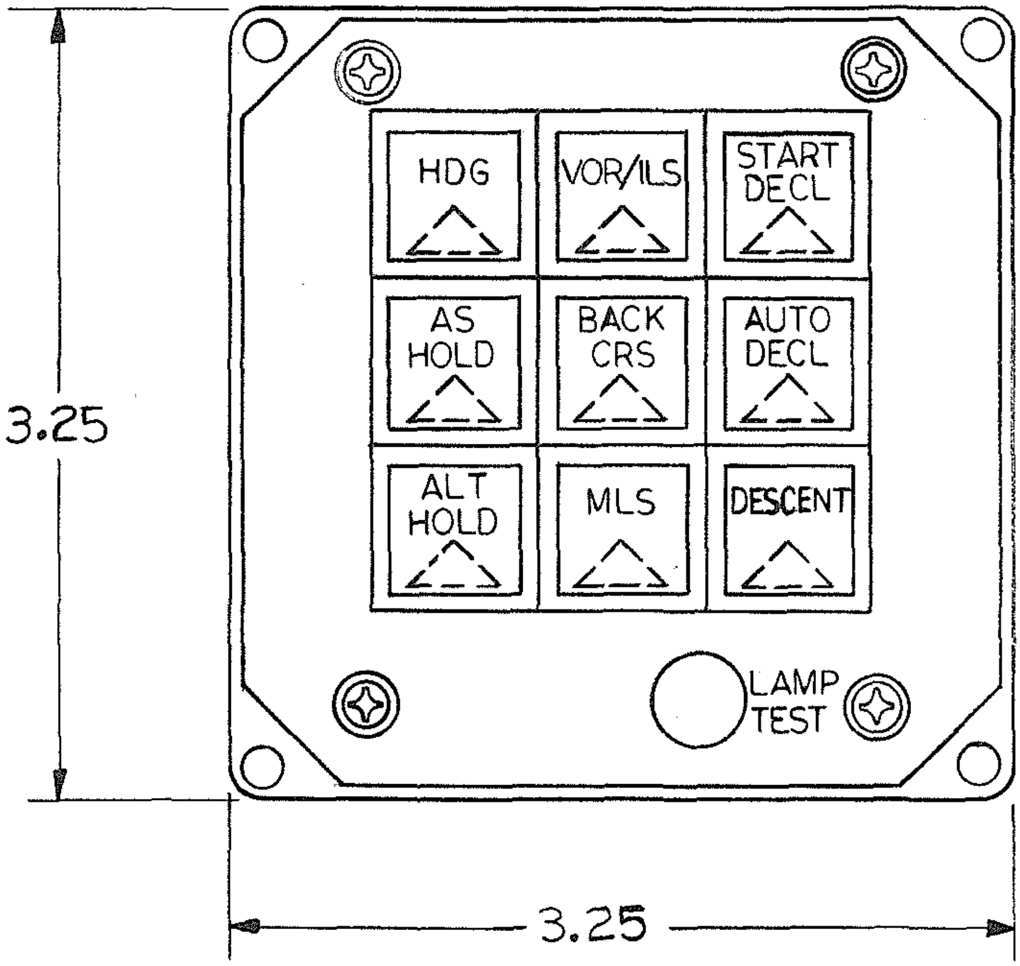

INITIAL APPROACH
INTERMEDIATE APPROACH
FLIGHT PLAN ALTITUDE
PROC. TURN
MISSED APPROACH
FINAL APPROACH
500 FEET RADIO ALTITUDE
150 FT RADIO ALT
APPROX 3 NM DECELERATION
5 NM
7 NM

FIGURE 1



NOTE: When both computers are on and operating, the full triangle will be lit for the mode selected. If one computer is off or inoperative, half the triangle on that side will not be lit.

FIGURE 2
FDC MODE SELECT PANEL
P/N 128840

The standard 5-inch ADI (Fig. 3) includes the Flight Director command cues, raw data for glideslope and localizer, as well as a Turn and Slip indicator and rising runway. Both Go-Around and Decision height warning light are also included.

The Horizontal Situation Indicator (HSI) (Fig. 4) provides a glideslope pointer, dual Bearing pointers, a course readout and distance information. The system mechanization provides remote transfer of the Heading and Course settings from one HSI to another. This enables the First Officer to set the next heading or course, which then can be transferred to the Captain's HSI when he requires the new information.

A separate Navigation Mode Select Panel (Fig. 5) enables both pilots to select any desired combination of VOR and/or ADF bearing information on the dual HSI bearing pointers. If a NAV/ILS failure occurs, the Flight Director System will be disabled in the failed mode on one side only. Because the NAV receiver signals are crossed over for the ADI glideslope and localizer pointers, cross-check information of ILS raw data is still available on the failed side. This feature also provides a cross-check to ensure that both NAV receivers are performing and set correctly under normal conditions. Otherwise, both Flight Director and NAV systems are completely separated and a failure on one system will not affect the other apart from losing glideslope and localizer raw data on the ADI.

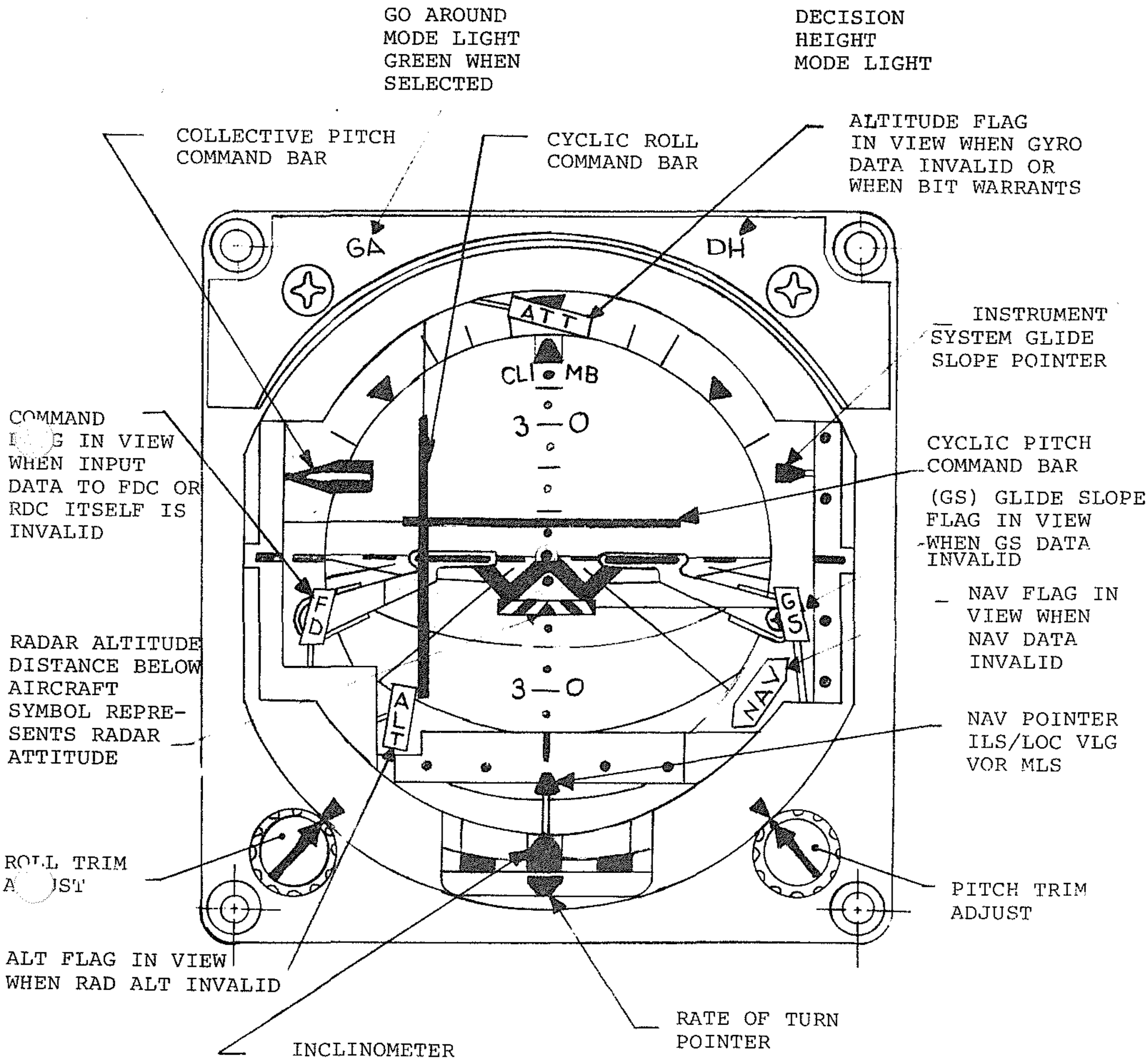
3. To reduce the workload en-route and in controlled areas Barometric Altitude Hold, Airspeed Hold and Heading Hold are provided. Heading and Course can be preset by the First Officer on his HSI to be transferred to the Captain's HSI when required. This feature will reduce the workload and the chance for error in controlled areas.

The introduction of an HSI instead of the separate Radio Magnetic Indicator (RMI) and Omni Bearing Selector (OBS) as used in the Kaiser evaluation (ref. 3) further reduces the instrument scan and provides for easier navigation.

III. Technical Background

The system described in the above, which is being supplied by Astronautics Corporation of America, has been designed and is being manufactured to install for supplemental type certification in the first two Sikorsky S-76's to be introduced into the KLM fleet. The system is not a one-of-a-kind prototype; it is a culmination of many years of flight director development specifically for helicopter application.

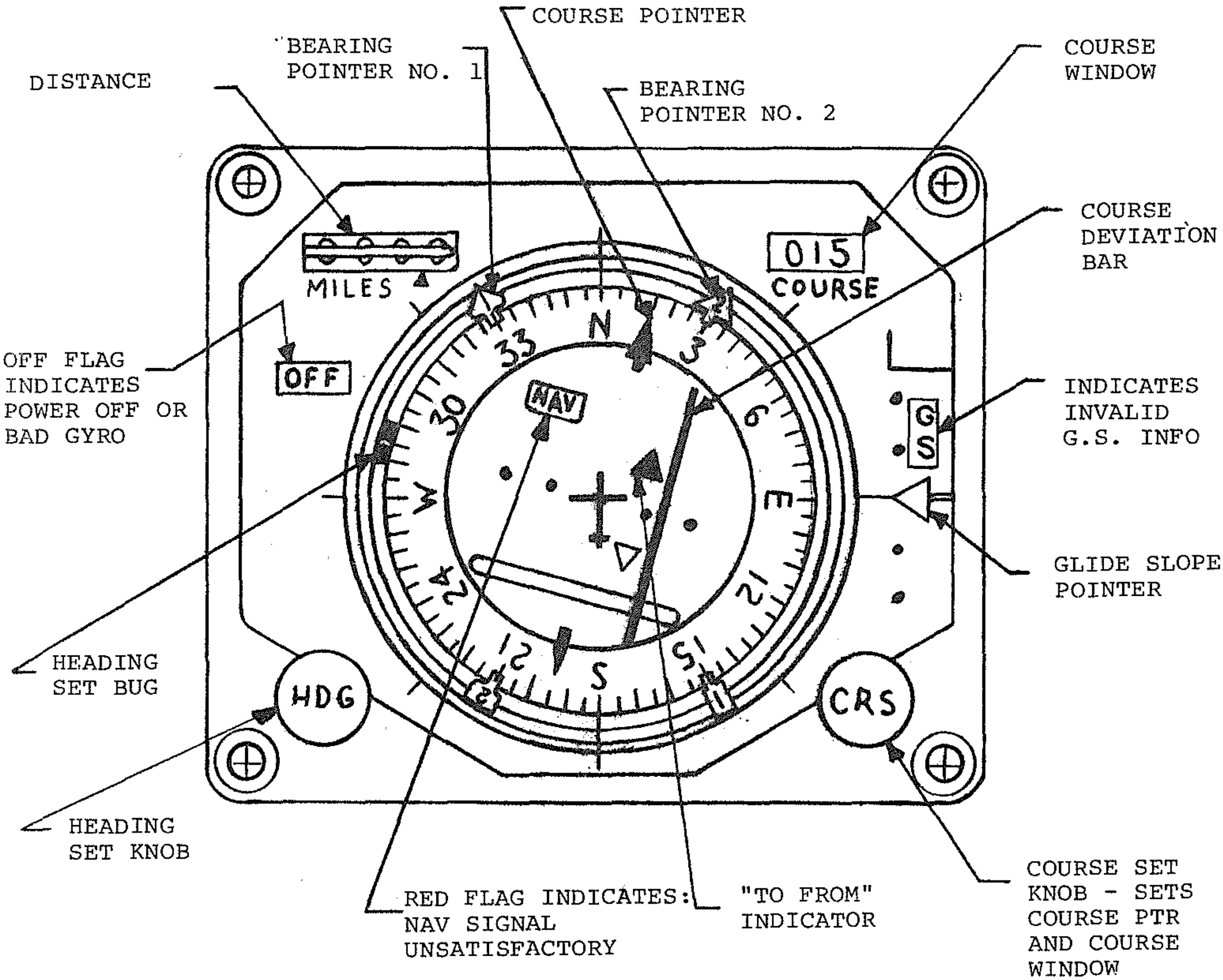
ACA has been in the Flight Director business for some 13 years and has produced Flight Director Systems on the production basis for many military aircraft. In 1972, ACA participated in a 3Q Flight



ACA 5" ATTITUDE DIRECTOR INDICATOR

P/N 129160

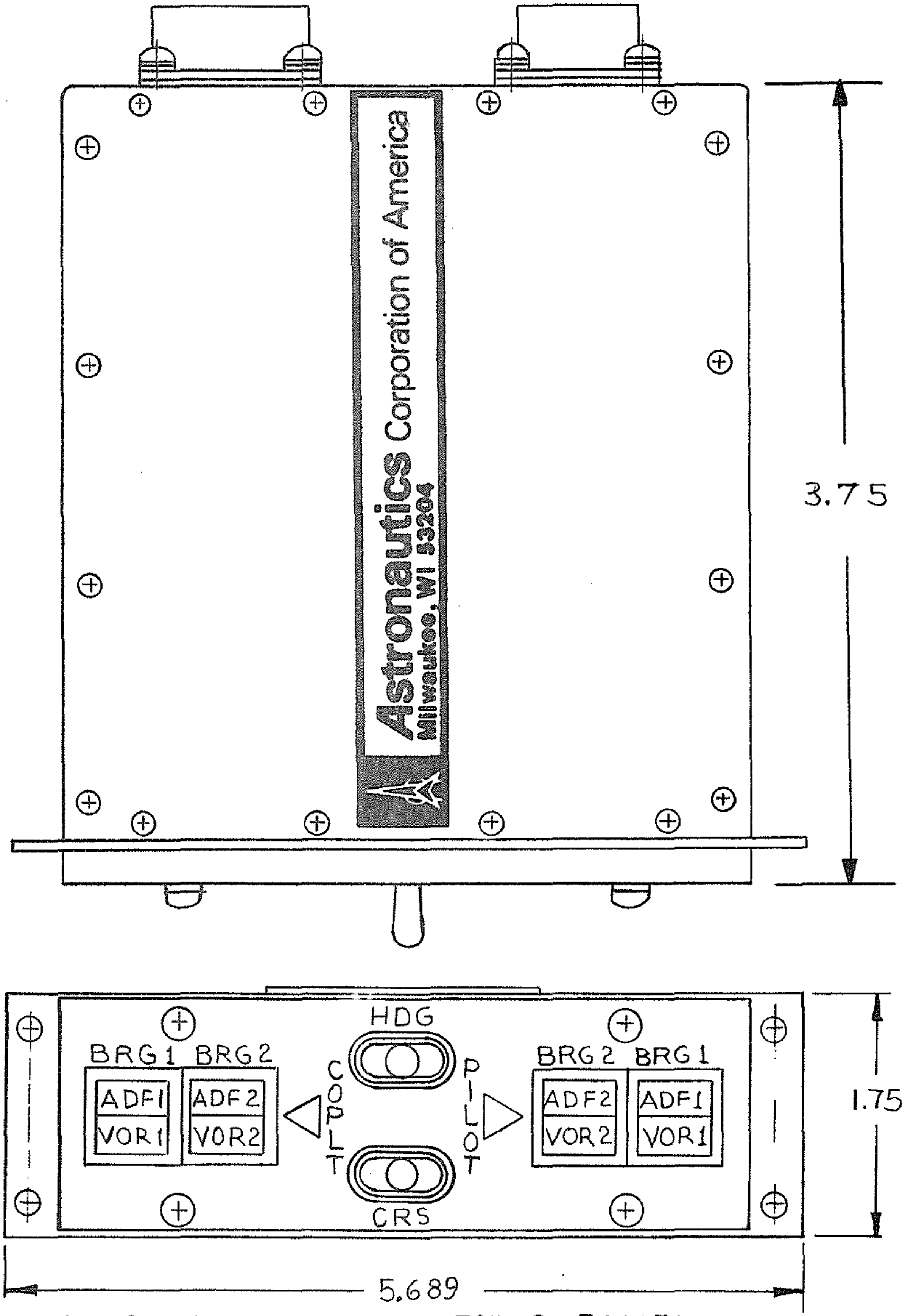
FIGURE 3



ACA 5" HORIZONTAL SITUATION INDICATOR

P/N 129400

FIGURE 4



NAVIGATION MODE SELECTOR PANEL
PN 129181
FIG 5

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Director system program conducted by the Army during which the basic principles of the 3Q Flight Director for helicopters were developed. These principles were applied to the equipment developed and qualified for the Black Hawk helicopter development program, and was evaluated by the U.S. Army in a competitive fly-off. ACA currently has a contract for the production of over 200 3Q Flight Directors for the Sikorsky Black Hawk. It is with this experience that the KLM system requirements were reviewed to determine what extent the Black Hawk Flight Director Computer (FDC) could be utilized in the S-76. It was also determined what other equipment or modifications of equipment were necessary to take full advantage of the S-76 IFR capability and meet the RLD requirements for CAT II operations without automatic coupling.

IV. System Description

Developing such a system is not as simple as installing a catalog item. It is unlikely that a catalog FDC would satisfy the specific requirements of the user and be compatible with this helicopter. Most catalog computers are of an older vintage, and although not functionally obsolete, they are usually rather ancient in today's fast moving electronics industry. The Flight Director system designed for KLM consists of 11 units of 8 different types. The heart of the system is the 3Q Flight Director Computer. Command information along with normal attitude information is displayed on the Attitude Director Indicator. Two are installed, one for the pilot and one for the co-pilot. Course, heading and distance information are displayed on dual Horizontal Situation Indicators. One Flight Director Computer Mode Select Panel is provided to select modes of operation. A Navigation Mode Select Panel is also used to select the desired navigation equipment from various sources. Three sensors are used, one to sense the collective stick position, one for airspeed and one for altitude. The integration of this hardware into a functioning system was the result of several pilot-engineer meetings during which time the most detailed scenarios were studied. The result was a precise system design specification to meet the specific mission requirements desired by KLM.

V. System Management

The Flight Director System is shown in block diagram form in Figure 6. Except for the compass heading gyro and the air data sensors, the system is completely dual, with each system component on the pilot's side duplicated with an identical but electrically independent component in the co-pilot's side. Each piece of equipment described earlier interfaces with its own (one for each side) VOR/ILS/GS Navigation Receiver, Vertical Gyro, Rate of Turn Gyro, Radio Altimeter and ADF Receiver. Each system is dedicated to one side of the aircraft with the exceptions of glideslope and localizer displayed on the ADI. These signals (and only these) are crossed over from the opposite system to provide an ILS raw data cross-check between the HSI and the ADI. Thus,

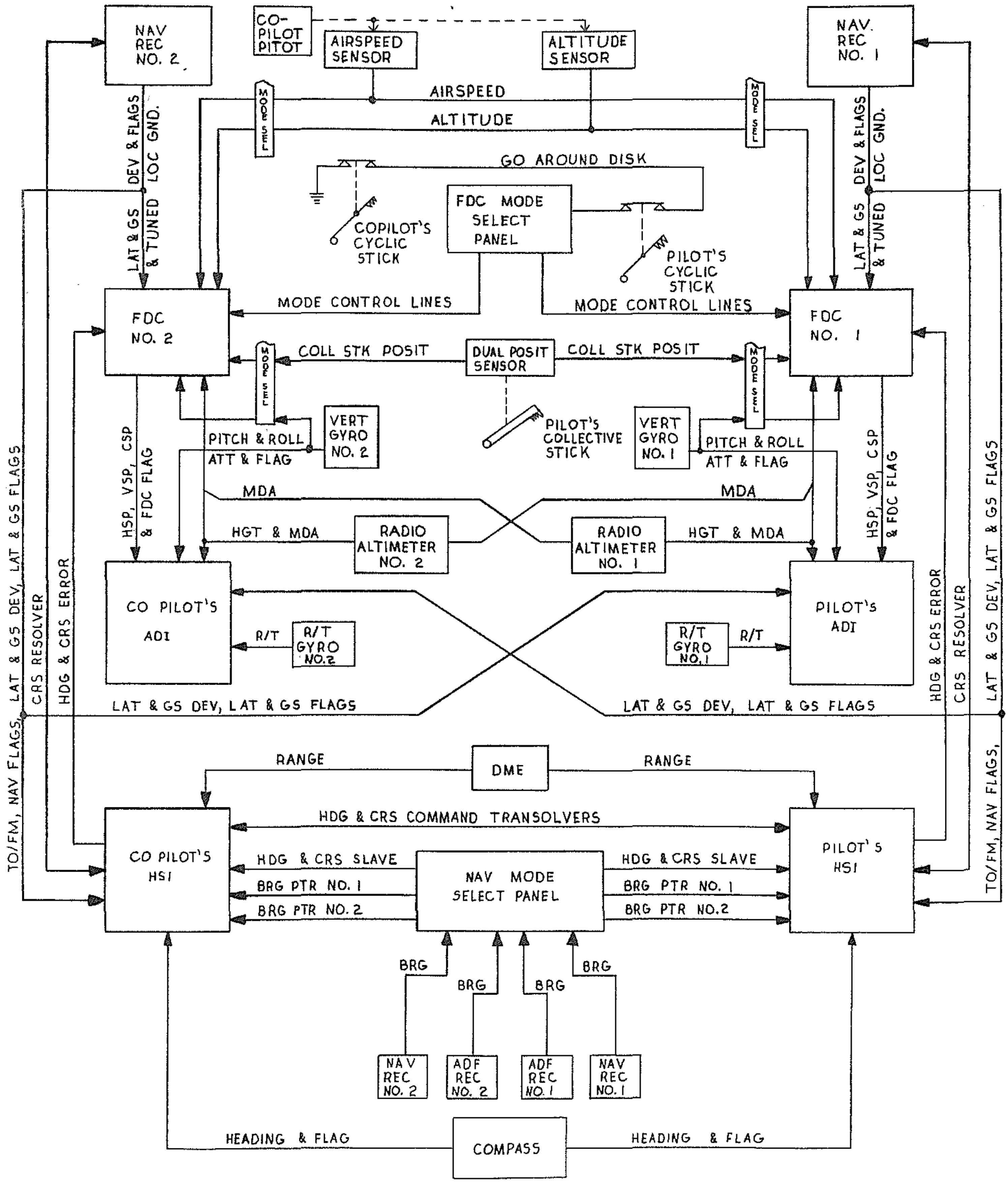

FIGURE 6
FDC SYSTEM INTERFACE BLOCK DIAGRAM

each system is a dedicated hard wired system, with very little switching required between sensors and components of the systems. The NAV Mode Select Panel, however, does provide for switching the Navigation and ADF receivers between the two bearing pointers on the HSI, both on the pilot's and on the co-pilot's side. It is also possible by means of transfer switches on this panel to transfer the co-pilot's selected heading or selected course from his HSI to the pilot's HSI and vice-versa. This feature allows one pilot to set up a new navigation problem on the HSI without interfering with the other pilot's use of his Flight Director System. Then, when desired, the new HSI settings can be transferred to his HSI with the flick of a switch.

When a Flight Director Computer mode is selected on the FDC Mode Select Panel, both computers are placed in the same mode, each controlled by an electrically independent set of contacts. Each computer lights up one-half of the mode selected triangle on the pushbutton switch of the Mode Select Panel. If one of the computers does not enter the selected mode, only one-half of the mode selected triangle symbol will light indicating clearly which computer is at fault.

VI. Mode Logic

The computer described in this paper has nine different selectable modes, many of which may be submodes of each other and in some cases can be submodes of submodes. Keeping track of all these switching sequences and priorities as well as all the validity requirements is accomplished by a single module called the "Mode Logic" board. Outputs from this Mode Logic board then control all the gain switching and signal routing on the computer boards. This Mode Logic board is required to perform a fairly elaborate electronic bookkeeping task and it is this board that must be modified to accommodate a change in mode switching philosophy.

Since the mission requirements vary from user to user and from aircraft to aircraft, it is usually this particular module in the computer along with the Mode Select Panel which will be different. The basic computer remains essentially the same except for gain, time constant and scaling changes to fit the aircraft dynamics. This leads us to the desired method of resolving gains and time constraints - simulation.

VII. Simulation

How are the gains and time constraints of a Flight Director Computer established for a particular aircraft? Usually it is done by the process of "guess--simulation--flight test--", sometimes by the process of "guess--flight test--guess again--flight test--good enough". The former process is by far the most desirable, but quite often the latter is what occurs in actual practice because to do simulation requires a knowledge of the aircraft dynamic equations. Many times this information is not available, or if it is available, it isn't accurate. Frequently the airframe manufacturer refuses to divulge any aircraft dynamics data, giving "proprietary information" as the reason. However, even approximate aircraft data is better than none because often the flight test data can be used as a feedback device to tune up the aircraft simulation to a point where a reasonably good optimization can be carried out. In the case of KLM's S-76, the second process will be used, but with a variation. The original guess will be very well educated as the result of previous experience on other helicopters. In addition, inflight adjustable pots will be installed in the first Flight Computer and used to establish the critical gain parameters on the initial flights. After that, it's a matter of flying in different combinations of conditions until the optimum gains have been established and verified. Armed with this data, we can specify the fixed components for installation in the production units.

VIII. Engineering Considerations

To meet the operational requirements as specified by KLM, a complete analysis of the system and its capabilities were made. Modes of operation and their performances were matched against KLM requirements. With regard to the Flight Director Computer itself, the computer control laws have been known for many years and the only truly inventive feature about them is the way in which they are mechanized electronically. However elegant mathematical models are, they suffer some shortcomings when mechanized with actual electronic hardware and are forced to cope with real, less than ideal, sensor inputs from the outside world. Some typical examples follow:

(a) Sensor Standardization

An extreme example of this is the ILS system in use in the United States where the localizer deviation sensitivity can differ by almost 100% between two airports. In the older ILS installations the localizer sensitivity is typically 60 mv/deg and could be as low as 50 mv/deg not counting permissible tolerance errors, which would make it even lower. In the newer ILS installations, the localizer sensitivity is made a function of runway length and can be as high as 100 mv/deg, not counting tolerance errors which would make it even higher. In the southwest United States, for example, there are two airports with runways exceeding 10,000 feet located within a few miles of one another (Edwards and Palmdale) whose ILS localizer sensitivities are 60 and 97 mv/deg respectively. This is one example of where the same input information to the computer represents two different things, and yet the computer performance must be equally good in both cases.

(b) Sensor Interface

Another example concerning the sensor selection is the computer interface with the VOR and TACAN navigation receivers. Due to the mechanical nature of the detectors in the older TACAN and VOR receivers, they generated a peculiar kind of low frequency noise which overlapped the signal spectrum. In order to accommodate for this noise, certain compromises in the computer control loop dynamics must be made which are not required (and are even detrimental) when using the modern day digital based navigation receivers. Nevertheless, the computer must be able to accommodate either case. In some cases, the computer must be able to handle both situations as in the case where both a TACAN set with an analog converter and a modern VOR receiver are used on the same aircraft.

Notwithstanding the fact that a well-designed computer should be capable of utilizing a variety of sensor inputs, there is a limit to what the computer can be asked to do given a particular set of input parameters, since in the ultimate analysis the computer performance cannot be much better than the input data. This means that when a Flight Director System is being put into an aircraft, the characteristics of the input sensors must be considered and if a choice is possible, we must choose those with characteristics compatible with the system.

(c) <u>System Compatibility with Helicopters</u>

Not all sensors can be taken right out of a fixed wing and installed in a helicopter. A very good example of this is the use of VOR receivers without modifications to handle rotor modulation of the radio signals. Some of the older VOR receivers, perfectly adequate for fixed wing application, perform so badly in a helicopter environment that even raw data pilotage is impossible. To try and couple this type of signal to a Flight Director Computer and expect acceptable performance is an almost hopeless task.

The point being made is that there are very many problems peculiar to helicopter operation which have been addressed and solved to some degree and they should be taken into consideration. The selection of sensors interfacing with the Flight Director Computer is one of the two things that has the greatest impact on the mechanization of the computer; the other is mode requirements. The sensor compabibility problem which is generally one of phasing and/or scaling can usually be handled with relative ease with only minor modification to the computer, if any at all. Adding a new operating mode or rearranging the mode selection configuration usually requires a much more extensive modification.

IX. Coupling

What about Coupled Systems? More systems will be installed with this idea in mind. The coupling problem is relatively straightforward provided there is an adequate stability system in the aircraft to which the aircraft can be coupled. In the Flight Director discussed earlier in this paper, the coupling interface circuitry would be located in the Mode Select Panel which is designed to accommodate it. Even though the Flight Director and the stability system interact with one another, they are essentially two separate control loop problems. The outer Flight Director loop, however, requires a stable inner loop which is handled by a short-term stability system generally present in any reasonably sophisticated aircraft. When the Flight Director is operated in a coupled mode, the command signals must be amplitude and rate limited to prevent step inputs to the stability system which might otherwise result in "hard over" situations.

X. Some Controversies about Flight Directors

Not everyone sees eye-to-eye about how Flight Directors ought to work. A typical example is the matter of what the polarity of the collective command pointer should be. Traditionally, Flight Director command pointers have always been mechanized using a "fly-to" convention. This means that if the longitudinal command pointer goes up--fly up, if the lateral command pointer goes right--fly right, and by extension, if the collective command pointer goes up--fly up by increasing collective. This is the convention used in the KLM System. Most, but not all, pilots feel at ease with this scheme. There is, however, some preference for the opposite convention to be used for the collective pointer by some pilots, especially those with little or no previous flight director experience. This includes a fairly large group of U.S. Army pilots who are now transitioning from basic VFR helicopters to IFR equipped aircraft. It is not expected that this particular controversy will be resolved soon. The important thing is that the ACA computer can be set to fly to or fly from the collective command pointer.

Another item of interest and some difference of opinion concerns the question of which flight control, cyclic pitch or collective, should control the vertical modes. If, for example, the helicopter is at cruising speed, either airspeed or altitude hold or glideslope or vertical speed hold can be controlled through cyclic pitch. This is what is done on inexpensive 2-Cue Flight Directors which were originally intended to be operated only in a "fixed wing mode". If, however, two of the above modes must be controlled simultaneously, then control of the vertical mode must be accomplished with the collective. Therefore, in order not to change the function of a particular command pointer, all ACA 3-Cue systems use cyclic pitch exclusively for airspeed control and collective for vertical modes. In these systems, airspeed as well as vertical speed can be maintained at the same time, thus allowing the pilot to fly at precise altitude and airspeed required for safe instrument flight.

Another basic question is that of 2-Cue vs. 3-Cue. It boils down to whether or not the pilot needs a collective command to set his power with. Some who argue for the 3-Cue say a constant command for power is required. The counter argument is that experienced pilots know what torque is required to achieve the desired results, such as 40% torque for descent, 80% for cruise, etc. The point will be argued forever. The 3-Cue system surely adds flexibility such as deceleration modes and simultaneous Airspeed and Altitude Hold. Whether to use a 2-Cue or 3-Cue system is a management/ operational decision.

XI. New Generations

What will the new generation Flight Directors be like? The trend is toward digital mechanization. Digital Flight Director computers already exist, but they are still more costly and more complicated than their analog counterparts, primarily because of the analog to digital to analog interfacing required to use them with existing avionics equipment. However, the ever-increasing availability of digital output sensors and especially the advent of the Microwave Landing System (MLS) is beginning to change this picture. Mechanization of the control laws will be different in the Digital Flight Director computers. They will incorporate alogrithms and error correcting control law mechanisms compatible with digital data processing techniques rather than the analog techniques now used. The MLS system, incidentally, will provide for a higher degree of precision on the performance of the Flight Director than was possible with the ILS system because MLS will provide a co-located MDE (range) signal which is not available with the ILS system.

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